1-1-1976

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Reprinted from

Symposium on

Machine Processing of

Remotely Sensed Data

June 29 - July 1, 1976

The Laboratory for Applications of
Remote Sensing

Purdue University
West Lafayette
Indiana

IEEE Catalog No.
76CH1103-1 MPRSD

RESOURCE INVENTORY USING LANDSAT DATA FOR AREAWIDE WATER QUALITY PLANNING

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I. ABSTRACT

As part of the national effort to improve water quality, Section 208 of the Federal Water Pollution Control Act Amendments of 1972 provides regional planning agencies with the opportunity and funds to conduct areawide water quality management studies. The Triangle J Council of Governments (Triangle J) was the first regional planning agency to receive funds to conduct such a study. Triangle J's 208 work plan focuses on the interrelationships of water quality, land use, and environmental resources with the generation and evaluation of alternatives for solving point and non-point source water quality problems.

Triangle J utilized LANDSAT imagery to provide an essential data base for major portions of the 208 inventory of existing resources, as well as for input data in modeling the region's water quality and future development patterns.

The inventory of the region's resources was obtained for the 1,750 square mile study area through the computer processing of LANDSAT computer compatible tapes. Ten land cover categories were interpreted at a detail of 0.44 hectares (1.1 acres) and included three developed categories, four forest types, agricultural-managed lands, bare soil, and water. The resulting products included color-coded overlays for each category at a ratio scale of 1:96,000 (1" = 8000'), color composite map of all categories at the same scale, and a computer tape containing land cover data for each of 54 USGS 7½ minute quadrangles by 50 meter grid cells.

The completed inventory was accomplished in less than three months at a cost of approximately $4.00 per square mile.

II. BACKGROUND

The Federal Water Pollution Control Act Amendments of 1972 initiated a coordinative approach for addressing the problems of water pollution. Provisions of this act provided for federal, state, and areawide programs with financial support from the Environmental Protection Agency (EPA). Areawide Water Quality Management Planning, termed 208 by the section designation, for the first time enabled sub-state regional agencies to plan for improved water quality while concurrently addressing the land use, environmental, and organizational aspects which are directly related to solving the problem.[1]

The Triangle J Council of Governments, in May of 1974, became the first regional planning agency to be granted EPA funds to conduct a 208 water quality management program. As part of this pilot project, Triangle J spent eight months developing a comprehensive work plan for its program of study.[2,3]

Of primary importance in the work plan were the interrelationships of basic resource data with the generation and evaluation of alternatives. It was determined that the inventory of resources for the 208 study area would have to include various land use and forest categories, as well as maps and associated statistical data. Such an inventory would be utilized in describing existing land use and environmental conditions, and have input into the analysis of non-point sources of pollution or that caused by stormwater runoff. This data would have to be flexible for aggregation to a variety of planning units such as counties, census tracts, and watersheds, as well as be flexible for comparison with other resource data such as soils, topography, geology, and physical development patterns.

To accomplish this phase of the 208 effort, Triangle J was faced with the requirements of having to inventory its relative large study area, 1,750 square miles, within a short period of time with only a modest sum of money.

Triangle J had orthophoto 7½ minute quadrangle maps (OPQ's) at a ratio scale of 1:24,000 which were prepared for the area by the U.S. Geological Survey from 1973 aerial photography. The 208 area is included in all or portions of 42 of these quadrangles. The effort required to manually transform land use data from the quads into a uniform set of map overlays and digitally coded tapes (for merging with the other data) was determined to be too time consuming and expensive. For these reasons, Triangle J decided that the traditional techniques for land use inventory - based on interpretation of aerial photographs - were impractical on a regional level. To obtain the needed inventory, Triangle J turned to LANDSAT data and computer assisted interpretation techniques.

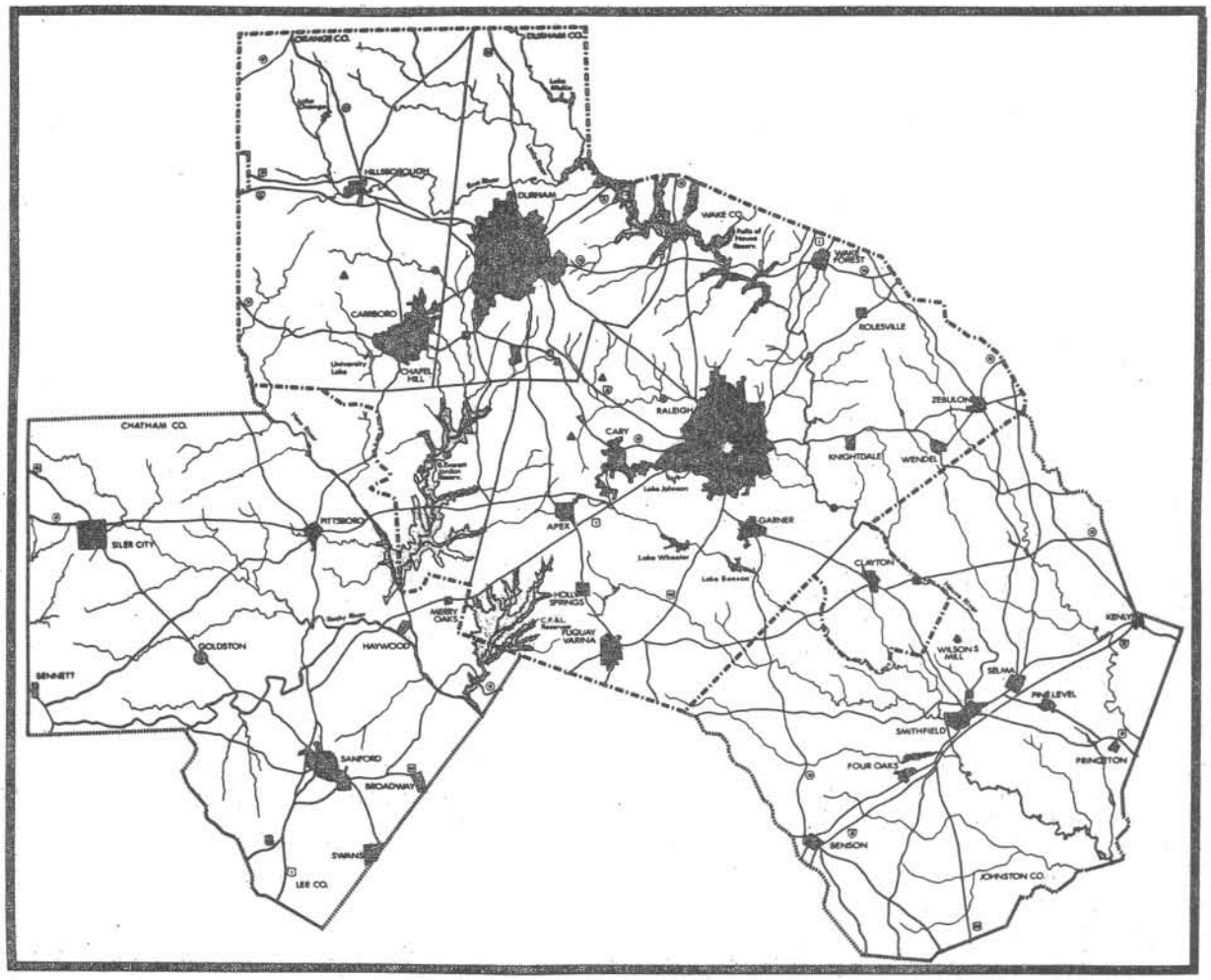

Figure 1. Triangle J Region with 208 Study Area Shown by Dashed Line.

III. THE STUDY AREA

The Triangle J region is located in the eastern portion of the North Carolina Piedmont. As shown in Figure 1, the designated 208 area is the central core of the six-county region and includes Orange, Durham, and Wake Counties and portions of Chatham and Johnston Counties. The 208 area covers 1,750 square miles (1,120,000 acres). Three major population centers (Raleigh, Durham, and Chapel Hill) and fourteen other municipalities provide a variety of employment and residential opportunities. The 208 area is within the watersheds of the Neuse River and Cape Fear River, but because many of the area's 5,000 miles of streams are headwater streams, water is not abundant and its quality is critical. Presently, there are only a few medium-sized water supply reservoirs and numerous small ponds but there are two major reservoirs proposed for the area with a total surface area exceeding 74,000 acres. Population in the 208 area increased 37% from 1950 to its 1970 level of 428,000. Conservative estimates indicate an anticipated population in the 208 area of more than 700,000 by the year 2000.

IV. COMPUTER ASSISTED INTERPRETATION

To initiate the LANDSAT data processing efforts, the 208 staff acquired from the EROS Data Center a computer print-out of all available LANDSAT scenes covering the study area. The list was screened firstly on the basis of coverage of the region - most of the scenes excluded small portions of the study area - and secondly on the basis of cloud cover and quality as it was indicated on the print-out. Only three scenes were selected as potentially useful and these were ordered in photographic form (Band 5) at a ratio scale of 1:250,000. The LANDSAT scenes (October 25, 1973; February 10, 1974; and February 14, 1975) were examined more closely and the October 25, 1973 scene was selected as having the least cloud cover, highest quality, and best coverage of the study area. Additionally, the date of this scene closely corresponds with the date of the aerial photography used for OPQ preparation, February, 1973. This LANDSAT scene was ordered in the 9-track 800 bpi computer compatible tape (CCT) form.

Triangle J contracted with Bendix Corporation, Aerospace Systems Division in Ann Arbor, Michigan to provide all computer softwear services for image analysis and product generation. The basic elements of the Bendix processing system include: a Bendix Datagrid Digitizer® System 100 for digitizing geographical or map data; a Bendix Multispectral Data Analysis System (M-DAS) for the analysis of LANDSAT computer compatible tapes; and an Optronics P-1500

model 30D film recorder for the production of land cover overlays and images from the LANDSAT tapes.[4,5]

Training areas of at least 16 hectares (40 acres) or more were delineated prior to image analysis by the 208 staff using the OPQ's and field inspection. At least three training areas of known ground cover for each of the desired categories were marked on the OPQ's. Staff participated in the analysis by assisting in the location of the training areas on the M-DAS TV monitor and checking category classification during play-back. Invaluable tools in this effort were: 1:250,000 LANDSAT Band 5 scene; 1:100,000 color enhanced scene; OPQ aerial photographs; and staff knowledge of the study area. Table I shows the relationship between the selected training sets and the percentage of data points categorized in the respective groups.

Nineteen categories were classified and later aggregated into ten land cover types. These ten land cover categories were interpreted for the study area at a detail of 0.44 hectares (1.1 acres). Included were three developed categories, four forest types, agricultural/managed land, bare soil, and water. The categories, their definition, and assigned color are listed below.

- High Density Developed: Developed areas with high concentrations of impermeable surface and no vegetation, such as central business district and high density industrial, commercial, and residential areas (purple).
- Medium Density Developed: Developed areas with medium concentrations of impermeable surface and limited vegetation including medium density commercial and residential areas (magenta).
- Low Density Developed: Developed areas with very low concentrations of impermeable cover and 30% to 40% vegetation, including single family residential and rural development (yellow).
- Agricultural/Managed Lands: Active cropland, tended pasture land, and managed areas with grass type cover such as golf courses and major highway interchanges (brown).
- Bare Soil: Areas with bare soil exposed such as plowed or working agricultural fields and areas undergoing construction (gray).
- Upland Hardwood: Forests dominated by oaks and hickories found in areas which have been relatively undisturbed for over 100 years (light green).
- Pine Forest: Forests dominated by pines found in areas which have been cleared for use within the last 60 to 80 years (blue).
- Mixed Forest: Forests with varying mixes of deciduous and evergreen trees in areas in successional transition from pine to hardwood (orange).
- Bottomland Hardwood: Forests dominated by hardwoods including sycamore, birch, maple, and oak located in low-lying areas which are subject to periodic flooding (blue-green).
- Lakes and Ponds (Water): Various categories of depth and sediment concentration were combined (dark blue).
- Uncategorized: Small areas which were not represented in the above ten categories. Less than 1.0% of the study area (black).

The resulting products included:

- color-coded overlays of the categories at a ratio scale of 1:96,000;
- negatives and positive transparencies for each of the categories at the same scale;
- reduced negatives and positive transparencies ($8\frac{1}{2}$"x11" format) for each of the categories;
- color composite map showing all categories at a ratio scale of 1:96,000; and
- 9-track 800 bpi tape containing data for 54 USGS $7\frac{1}{2}$ minute quadrangles (OPQ's) where each 50 meter grid cell was coded as to land cover categories.

Figure 2 indicates the location of the $7\frac{1}{2}$ minute quads for the study area and shows the reduced transparency for the water category.

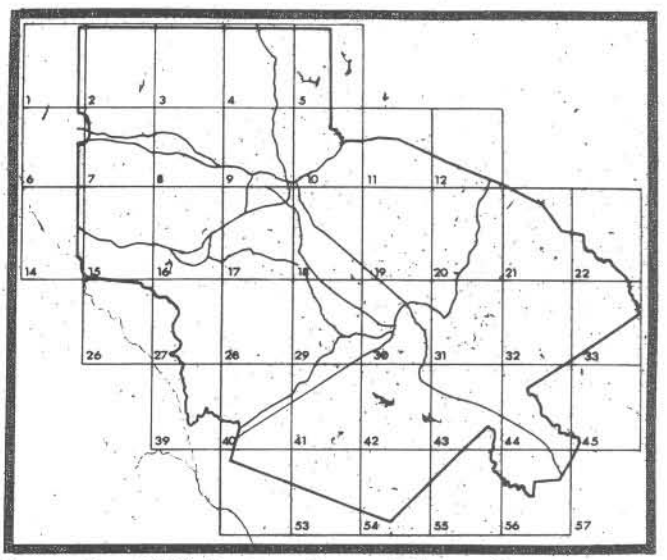

Figure 2. USGS Quadrangles and Water Category.

V. USER APPLICATIONS

Other data generated in the inventory phase of the 208 study were such that correlation of such data to that generated from LANDSAT analysis would be possible. All mapped information (topography, geologic features, watersheds, census tracts, culture, etc.) is displayed on reproducible base maps at a ratio scale of 1:96,000. Triangle J has a tie-in with the Triangle University Computation Center. Staff has coded and can access numerous data sets such as soil suitability factors, percentage slope, depth to bedrock, land in public ownership, and demographic characteristics on a four-hectare (200 meter grid) basis for the study area. Correlation of all mapped and computer data is, therefore, significantly enhanced.

Table 1. Training Sets and Percent Categorized As Groups.

Training Set	Percent Categorized As Group																
	L.D. Dev.	Ag/ Manag.	Up. Hdwood	Lo. Hdwood	Pine	Water	H.D. Dev.	Water	Ag/ Manag.	M.D. Dev.	Water	Bare Soil	Bare Soil	Ag/ Manag.	Mixed Forest	Ag/ Manag.	Water
L.D.Dev.	91.67	8.33	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Ag/Manag.	-	100.00	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Up. Hdwood	-	-	90.62	9.37	-	-	-	-	-	-	-	-	-	-	-	-	-
Lo. Hdwood	-	-	8.11	72.97	-	-	-	-	-	-	-	-	-	-	18.92	-	-
Pine	-	-	-	-	97.50	-	-	-	-	-	-	-	-	-	2.50	-	-
Water	-	-	-	-	-	100.00	-	-	-	-	-	-	-	-	-	-	-
Water	-	-	-	-	-	100.00	-	-	-	-	-	-	-	-	-	-	-
H.D.Dev.	-	-	-	-	-	-	100.00	-	-	-	-	-	-	-	-	-	-
Water	-	-	-	-	-	0.93	-	99.07	-	-	-	-	-	-	-	-	-
Ag/Manag.	3.57	-	-	-	-	-	-	-	96.43	-	-	-	-	-	-	-	-
M.D.Dev.	-	-	-	-	-	-	-	-	-	100.00	-	-	-	-	-	-	-
Water	-	-	-	-	-	-	-	-	-	-	100.00	-	-	-	-	-	-
Bare Soil	-	-	-	-	-	-	-	-	-	-	-	100.00	-	-	-	-	-
Bare Soil	-	-	-	-	-	-	-	-	-	-	-	-	100.00	-	-	-	-
Ag/Manag.	-	-	-	-	-	-	-	-	-	-	-	-	-	100.00	-	-	-
Mixed Forest	-	-	-	12.50	-	-	-	-	-	-	-	-	-	-	87.50	-	-
Ag/Manag.	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	100.00	-
L.D.Dev.	100.00	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Water	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	100.00

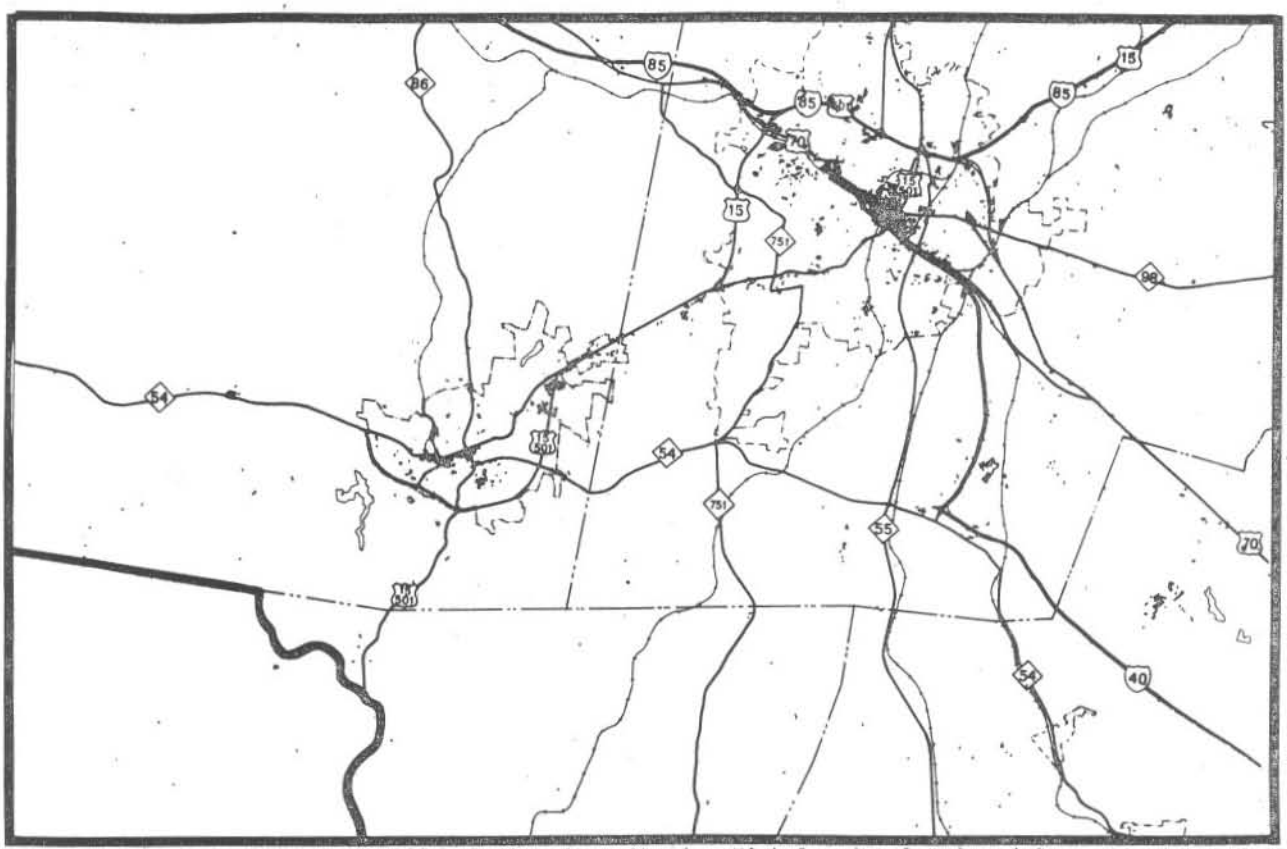

Figure 3. Chapel Hill - Durham Area Showing High Density Developed Category.

A. Water Quality Considerations

While many factors influence water quality, a dominant one is the use of land adjacent to and surrounding streams, lakes, and rivers. In order to quantify the water quality impacts resulting from stormwater runoff from various land uses, Triangle J established six water quality monitoring stations and eleven water quality sampling stations. The sampling stations were located in such a manner that they measured stormwater quality from a particular land use category in a particular drainage area or catchment. Specific land uses monitored were: single-family residential, multi-family residential, central business district, commercial, developed rural, and undeveloped rural. Other stations sampled larger drainage areas with several land use types. Water quality data from the monitoring and sampling stations were used to develop pollution coefficients for stormwater runoff from particular land uses.

Triangle J characterized each of the 85 catchments being studied as to the predominant land cover, percentage impervious cover, and area subject to erosion based upon LANDSAT generated overlays and topographic and stream maps of the region. Pollution coefficients and runoff characteristics from a particular land cover (i.e. high, medium, and low density developed; agricultural; bare soil) were used with other input data (soils, slopes, rainfall, area drained, etc.) to estimate the quality of stormwater runoff under existing conditions by using the Stormwater Management Model.[6]

B. Land Use Considerations

Prior to the work undertaken in the 208 study, no uniform base map of land use existed for the counties or the region they comprise. Base maps and data generated from LANDSAT helped fill this void and provided useful information for analyzing land use on a county and regional level.

A synoptic view of existing land cover for the region was provided by the composite base map at a scale of 1" = 8,000'. Relationships of developed areas versus agricultural or forested areas were examined and significant differences in type and extent land cover were noted.

Figures 3, 4, and 5 are photographs of the black and clear transparencies for the developed categories in the Chapel Hill-Durham area (original scale 1" = 8,000'). To indicate relative levels and locations of development, Figure 3 shows only high density developed land cover which is concentrated within municipal boundaries and along transportation corridors while Figure 4 shows high and medium density developed area. Figure 5 shows high, medium, and low density developed area. Developed area, urban and rural, can be readily noted as it groups around primary and secondary transportation routes. The extent and juxtaposition of undeveloped area (white), which is predominately forested and agricultural, can also be seen.

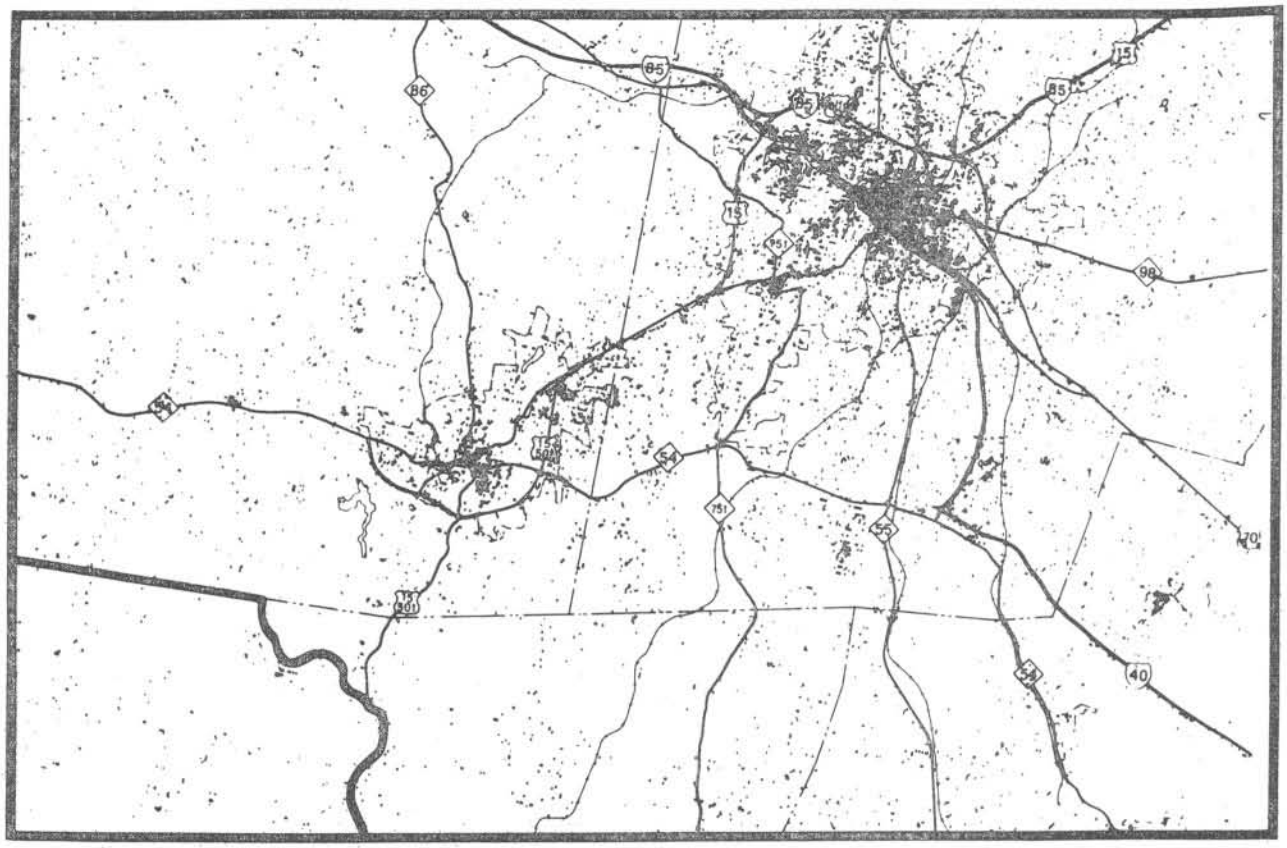

Figure 4. Chapel Hill - Durham Area Showing High and Medium Density Developed Categories.

Figure 5. Chapel Hill - Durham Area Showing High, Medium, and Low Density Developed Categories.

Table 2. Land Cover in Hectares for Durham County and Area by USGS 7½ Minute Quadrangle Maps.

Category	USGS Quadrangle Map[a] (4) Durham North, NW	(5) Durham North, NE	(9) North-west Durham	(10) North-east Durham	(17) South-west Durham	(18) South-east Durham
H.D.Dev.	19	44	308	50	325	115
(%)	(<1%)	(<1%)	(2%)	(<1%)	(2%)	(1%)
M.D.Dev.	225	251	1,144	408	1,059	407
(%)	(1%)	(2%)	(7%)	(3%)	(7%)	(3%)
L.D.Dev.	1,902	1,490	2,410	2,450	2,570	2,360
(%)	(12%)	(10%)	(16%)	(16%)	(17%)	(15%)
Ag/Manag.	2,571	2,005	1,484	1,758	1,061	1,411
(%)	(17%)	(13%)	(10%)	(11%)	(7%)	(9%)
Water	76	366	91	78	101	76
(%)	(<1%)	(2%)	(1%)	(1%)	(1%)	(<1%)
Bare Soil	484	235	247	181	257	259
(%)	(3%)	(2%)	(2%)	(1%)	(2%)	(2%)
Up.Hdwood	3,396	2,781	2,638	1,866	1,373	1,867
(%)	(22%)	(18%)	(17%)	(12%)	(9%)	(12%)
Pine	2,456	4,227	3,221	3,279	2,851	3,626
(%)	(16%)	(27%)	(21%)	(21%)	(18%)	(23%)
Mixed Forest	2,531	2,606	1,967	3,175	3,088	3,061
(%)	(16%)	(17%)	(13%)	(21%)	(20%)	(20%)
Lo.Hdwood	1,757	1,413	1,907	2,179	2,817	2,313
(%)	(11%)	(9%)	(12%)	(14%)	(18%)	(15%)
Uncat.	22	21	21	15	6	13
(%)	(<1%)	(<1%)	(<1%)	(<1%)	(<1%)	(<1%)

[a] Numbers in parenthesis refer to quad location in Figure 2.

Statistical information for each category or combination of categories was available from the computer data tape. Land cover data for the six USGS quadrangles comprising Durham County are summarized in Table 2. Additional land cover data aggregations are also available by county, census tract, and catchment.

Alternative land use patterns were developed using the LANDSAT generated maps and data as a base. The land cover data was aggregated to a four-hectare PLUM grid cell (Statewide Planning and Land Use Management System).[7] Additional characteristics were also coded to this grid cell such as soil suitability, slope, floodplains, parks, areas in public ownership, and land already committed. In projecting land use in the 208 area, a Residential Allocation Model was used to allocate growth by census tracts.[8] The LANDSAT generated land cover data enabled the determination of the size and extent of developed and undeveloped land by census tract. By programming various constraints such as density, soil suitability, slope, critical environmental areas, and committed land, the projected population was allocated to the undeveloped area in a series of alternative land use patterns. Anticipated stormwater runoff problems of these future land use patterns were assessed for each catchment area by utilizing the input parameters to the Stormwater Management Model as previously described.

C. Environmental Considerations

Four categories of forest type were mapped with LANDSAT data as a means of defining vegetational resources and wildlife habitat in the region. The extent and distribution of these forest types indicate generally the historic use of an area, availability of wildlife habitat, possible existence of rare and endangered species, and locations of unique or natural areas.

Areas which have been cleared in the past for agricultural or timbering uses and subsequently abandoned, grow up in the first forest type in vegetative succession, the pine forest (Figure 6). Pine forests, the predominant forest type in this area, are later replaced by mixed pine-hardwood forests if left relatively undisturbed for about 80 to 100 years. Mixed forest offers more to wildlife in terms of habitat diversity than large tracts of pine. An area which is primarily hardwood forest is an area which has not been disturbed

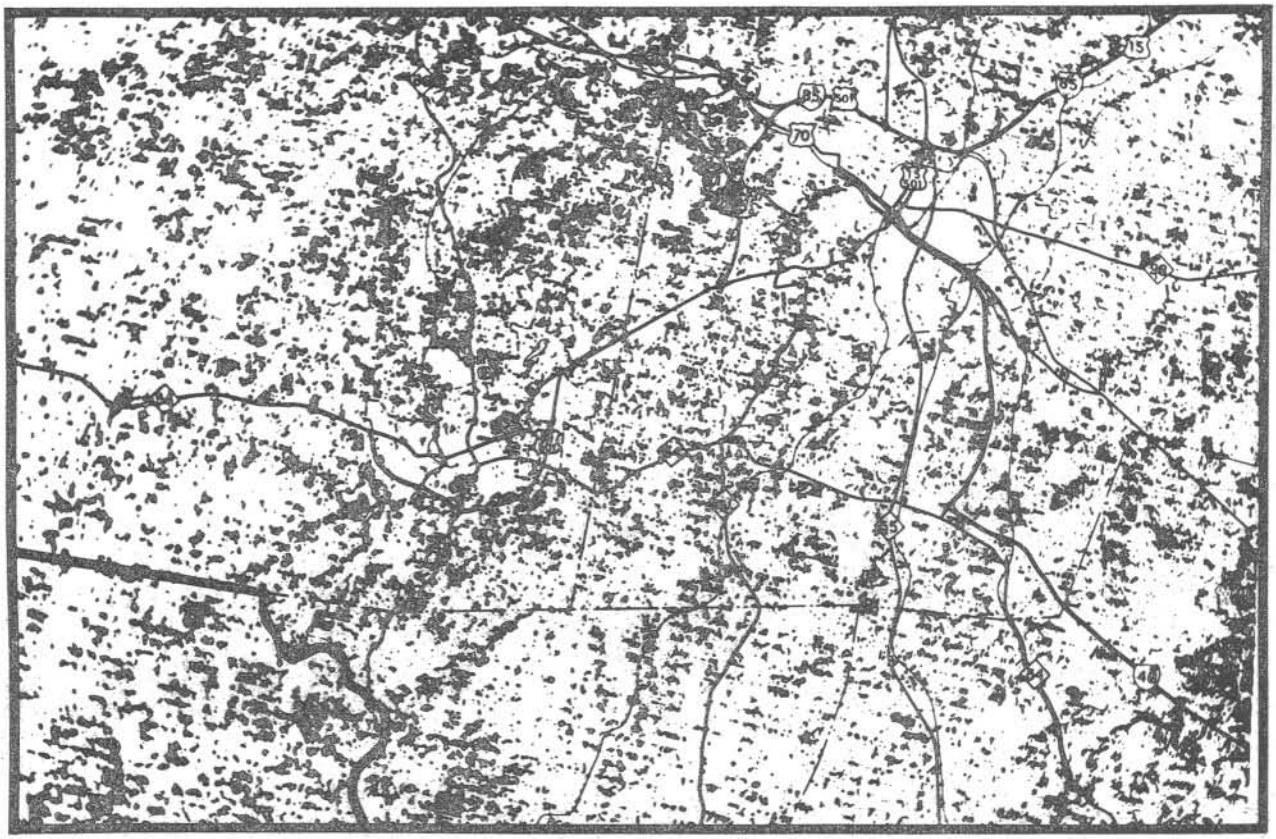

Figure 6. Chapel Hill - Durham Area Showing Pine Forest Category.

or has proceded through the 100+ years of vegetative succession to the climax forest. Upland hardwood forests in the 208 area are more likely in areas with poor soils for agriculture and/or with restrictive slope. Upland hardwood forests in Figure 7, for example, follow the ridge lines of mountains to the north and south of Chapel Hill. North facing slopes of these upland hardwood forests provide a unique habitat for rare vegetation. Bottomland hardwoods offer prime wildlife habitat in the 208 area and are concentrated along streams, particularly south of the Durahm-Chapel Hill area (Figure 8).

LANDSAT maps and statistical data enabled an inventory and analysis of these existing forest resources. Additionally, the environmental impact of proposed development and alternative land uses was assessed by determining the extent of disruption of wildlife habitat and the loss of forest resources caused by such development.

VI. SUMMARY

By using the LANDSAT data as a base mapping and statistical tool, the entire 208 planning area was inventoried and scale corrected map overlays and a computer data tape were generated in less than three months. Overall classification accuracy of the categories was judged to be around 90% and the cost of processing the LANDSAT scene and generating the products was approximately $4.00 per square mile.

Triangle J's use of computer assisted analysis of LANDSAT imagery provided a significant alternative to base mapping with aerial photography. Overlays, composites, and statistical data were made available on a time, monetary, and manpower efficient basis. With these advantages at hand, staff time was turned toward analyzing and interpreting the data rather than simply producing it.

Products from the analysis of LANDSAT imagery have already been utilized to describe the region in terms of its over-all land cover. Drainage areas defined by land cover and topography have been established. Land cover data was matched with other data on a regional and sub-regional basis. Areas which are undeveloped and have the potential for urbanization have been identified. Significant differences in terms of forest cover and agricultural resources have been quantified.

Each of these uses has particular relevance to the Triangle J 208 water quality planning process. Uses of this LANDSAT data in other region-wide planning activities have already become apparent, particularly with the advantages of being able to update base information at a low cost. Interest, inside and outside the region, in this process for resource inventories indicate that the applicability of the LANDSAT imagery approach to mapping and data presentation will have continuing impact and importance.

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Figure 7. Chapel Hill - Durham Area Showing Upland Hardwood Forest Category.

Figure 8. Chapel Hill - Durham Area Showing Bottomland Hardwood Forest Category.

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